

ARMY RESEARCH LABORATORY



Evaluation of the IMPAC66 Shock Test Machine, Serial Number 118

Marshal A. Childers

ARL-TR-2840

OCTOBER 2002

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturers' or trade names does not constitute an official endorsement or approval of the use thereof.

DESTRUCTION NOTICE Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-2840

October 2002

Evaluation of the IMPAC66 Shock Test Machine, Serial Number 118

Marshal A. Childers

Weapons and Materials Research Directorate

Approved for public release; distribution is unlimited.

ACKNOWLEDGMENTS

The author thanks the following people for their expertise, guidance, and assistance during the collection and post-processing of data for this study:

- Mr. Mike Nair (Oak Ridge Institute for Science and Education) assisted with the shock tests and developed some macros that made the post-processing more efficient.
- Mr. T. Gordon Brown (ARL) and Mr. John McLaughlin (DSI) provided advice about shock testing techniques, data acquisition, and data post-processing.
- Mr. Ron Wayne (DSI) machined the accelerometer mounting fixtures used in this study.
- Mr. Nate Hundley and Mr. John McLaughlin (both of DSI) repaired accelerometer cables.
- Mr. T. Gordon Brown and Mr. Dick McGee (DSI) are acknowledged for the careful technical review of this report.

Contents

1.	Introduction	1
2.	Experiment Description	1
2.1	Shock Test Machine	1
2.2	Acceleration Measurement	4
2.3	Shock Pulse Characterization	5
3.	Results	7
3.1	Programmers and Accelerometers	7
3.2	Filters	15
4.	Summary and Conclusions	17
	References	20
	Report Documentation Page	21

Figures

1. MTS IMPAC66 shock test machine, serial number 118	2
2. Felt programmers: (a) 0.25 inch thick and (b) 1 inch thick	3
3. Typical shock pulse for a felt programmer: (a) 0.25 inch, (b) 0.5 inch, and (c) 1 inch	6
4. Maximum accelerations for 23-inch drops on the 0.25-inch programmer	8
5. Shock pulse durations for 23-inch drops on the 0.25-inch programmer	9
6. Maximum accelerations for the conditioned 0.25-inch programmer	9
7. Shock pulse durations for the conditioned 0.25-inch programmer	10
8. Maximum accelerations for 47-inch drops on the 0.5-inch programmer	11
9. Shock pulse durations for 47-inch drops on the 0.5-inch programmer	11
10. Maximum accelerations for the conditioned 0.5-inch programmer	12
11. Shock pulse durations for the conditioned 0.5-inch programmer	12
12. Maximum accelerations for 94-inch drops on the 1-inch programmer	13
13. Pulse durations for 94-inch drops on the 1-inch programmer	14
14. Maximum accelerations for the conditioned 1-inch programmer	14
15. Pulse durations for the conditioned 1-inch programmer	15
16. Effects of cut-off frequency on maximum acceleration	16
17. Effects of cut-off frequency on shock pulse duration	16

Table

1. Accelerometer specifications	4
---	---

1. Introduction

The purpose of this evaluation is to calibrate and identify the performance capabilities of the MTS¹ IMPAC66 high velocity acceleration (HVA) shock test machine, Serial Number 118. This unit is currently situated at the U.S. Army Research Laboratory (ARL) in Building 4600 (Lab 1252) at Aberdeen Proving Ground, Maryland, and is used by ARL's Weapons and Materials Research Directorate. The IMPAC66 shock test machine was designed to simulate high acceleration and/or high velocity scenarios. Shock tests performed at ARL are used to determine the survivability of electronic sensing packages when these are exposed to various launching environments. Typical accelerations associated with gun-launched munitions can range from 1500 g's to 30,000 g's². The results provided in this report will be used as a reference for the shock test applications performed within ARL. This work will also be used as a benchmark for post-refurbishment and post-maintenance performance verification.

The IMPAC66 shock test machine, Serial Number 118, was evaluated for calibration and performance with respect to current usage at ARL and for future reference in testing and maintenance functions. Several series of experiments were conducted to determine the effects of felt programmer thickness, accelerometer performance, and signal conditioning on measured shock pulses. Specifically, experiments were performed to determine the effects of three programmer thicknesses, four cut-off frequencies, and two accelerometer measurement ranges.

2. Experiment Description

2.1 Shock Test Machine

The IMPAC66 HVA shock test machine, Serial Number 118, was manufactured circa 1969. The mechanism consists of a 33-pound high strength forged aluminum table that is accelerated with bungee cords onto a 450-pound steel reaction mass (see Figure 1). This mass is supported by a hydro-pneumatic suspension system. Before each test, care was taken to ensure that all bolts on the test fixture, table, and brakes were secure to ensure proper function of the machine and to reduce mechanical noise in acquired shock pulses. It is common for the bolts that connect the lifters to the seismic base to loosen during shock tests with accelerations levels in the range of

¹ Not an acronym

² 1 g is equal to the earth's gravitational acceleration.

10,000 to 30,000 g's. The loosening of these bolts impedes the ability of the brakes to catch the table properly during rebound after the shock pulse has been produced.

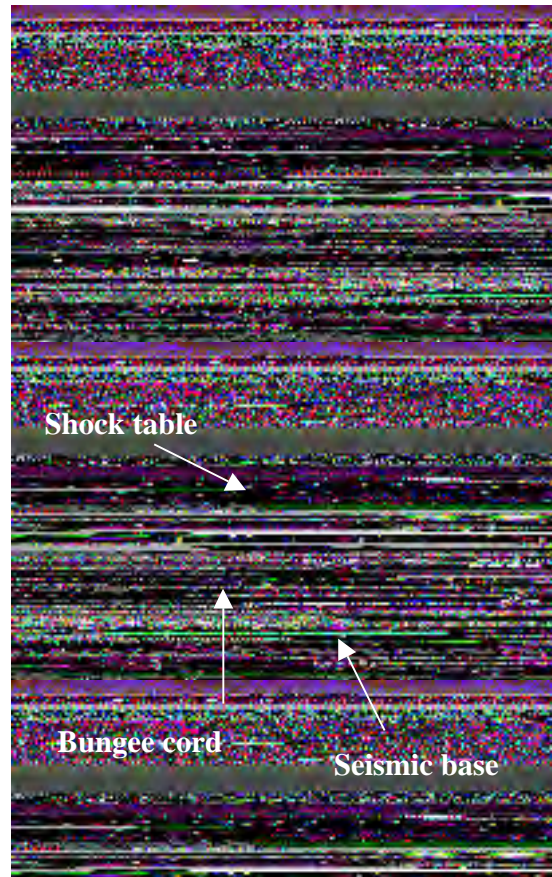
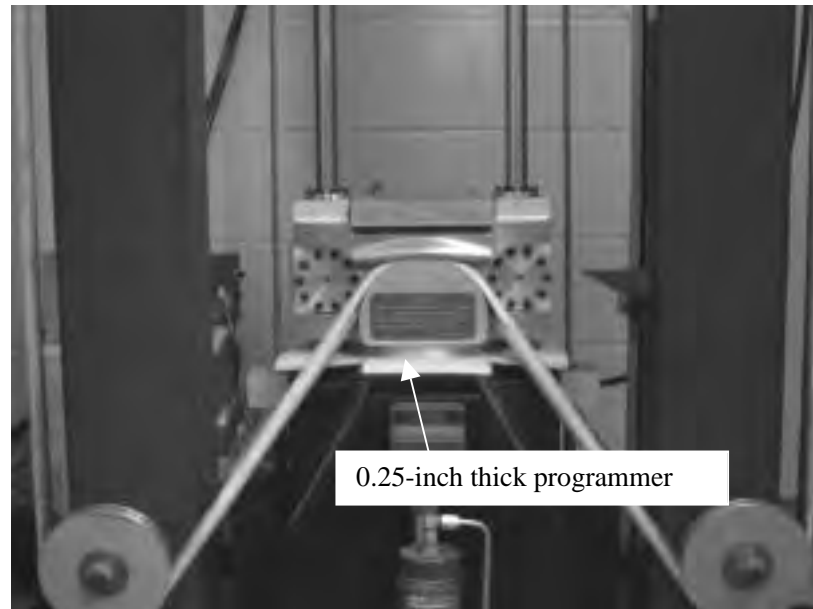


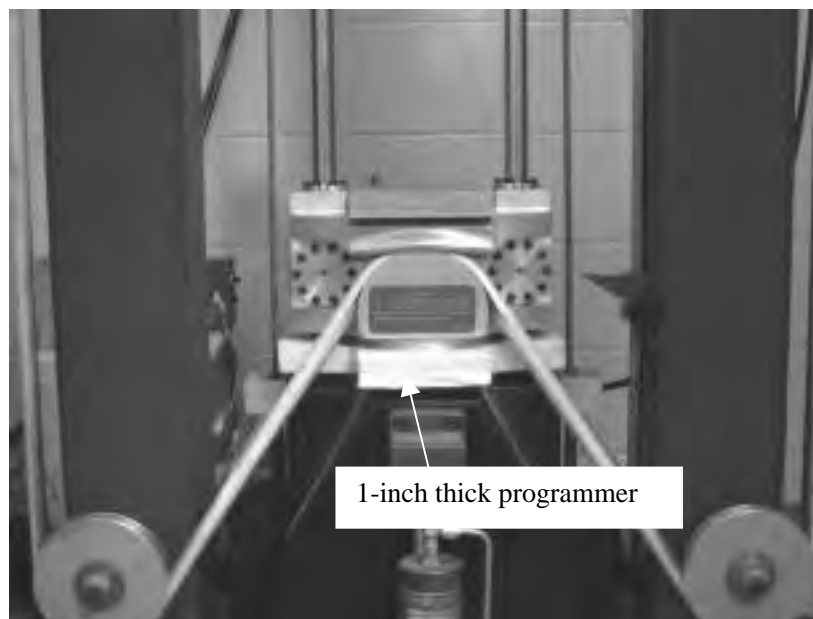
Figure 1. MTS IMPAC66 shock test machine, serial number 118.

In order to obtain a shock pulse of desired maximum acceleration and duration and to prevent damage to the shock test machine, it is necessary to place a programmer (shock-mitigating material) between the shock table and reaction base. This material has energy-absorbing characteristics, and typical programmers are constructed from felt or urethane materials. A third type of programmer, the universal programmer, uses pressurized air and is applicable for low accelerations (0 to 500 g's). The shock testing performed at ARL usually involves high acceleration applications and thus, the felt programmers have proved to be the most appropriate. High density felt, model F-1, available from McMaster Carr, was the material used for programming all the shock pulses in this analysis. Tests were performed with 0.25-inch, 0.5-inch, and 1-inch felt pads. Figure 2 shows 0.25-inch and 1-inch felt programmers inserted between the shock table and reaction mass. The structural composition of the F-1 felt is such that shocks compress the pad and thus change the response with each successive shot. Inconsistencies in shock test results associated with the use of new programmers led to a method of preconditioning the felt pads in order to obtain consistent performance. After a number of shocks, compression

will cease so that subsequent responses become repeatable (the term “repeatable” as used in this report is defined as “the last several values are within 10% of the previous value”). A series of tests was conducted, starting with new felt and repeatedly shocking the material at a constant height until the measured maximum acceleration values became repeatable. When a repeatable level of maximum acceleration was reached, another series of tests was performed on the same felt pad over a range of prescribed drop heights.



(a)



(b)

Figure 2. Felt programmers: (a) 0.25 inch thick and (b) 1 inch thick.

2.2 Acceleration Measurement

The decelerations achieved during the shock tests conducted for this analysis were measured with PCB³ piezoelectric accelerometers. These devices produce a voltage when exposed to acceleration and this voltage is proportional to the acceleration by the particular accelerometer sensitivity. Two PCB accelerometer models were used for this study. The differences between the two accelerometers used in this experiment are that the PCB model 350B23 has an internal mechanical filter of 13 kHz and a measurement range of 10,000 g's. Table 1 provides the performance specifications for each accelerometer used in this study. Multiple accelerometer measurements on single tests were used to determine variation in accelerometer performance and to verify the acquired data. As many as four accelerometers of similar range and sensitivity were used to obtain the results provided in this report. The 100,000-g accelerometer (Model 350B21) was used for most shock tests in the acceleration range of 0 to 30,000 g's, which were conducted by ARL during the past 10 years. The shock test data obtained from the experiments described in this report achieved accelerations of approximately 500 to 30,000 g's. Given that the maximum operational acceleration of the IMPAC66 HVA shock test machine is 30,000 g's, tests were structured to maintain this limit. As shown in the results of this study, the achievable range of maximum acceleration and corresponding pulse durations depend on felt programmer thickness.

Table 1. Accelerometer specifications

Model Number	Serial Number	Sensitivity	Meas. Range	Resolution	Resonant Frequency
		(mv/g)	(G)	(G _{rms})	kHz
350B21	7227	0.050	100000	0.30	>200
350B21	7228	0.052	100000	0.30	>200
350B21	7232	0.050	100000	0.30	>200
350B21	7233	0.054	100000	0.30	>200
350B23	7903	0.400	10000	0.04	>100

To determine the effect of cut-off frequency on measured shock pulses, a series of tests was conducted so that the accelerometer signals from four PCM Model 350B21 accelerometers were fed to two-stage analog filters of 13-kHz, 30-kHz, and 50-kHz cut-off frequencies. The assignment of filters was such that increasing cut-off frequency corresponded to increasing accelerometer sensitivity. A PCB Model 494A single-channel signal-conditioning unit was used to apply power and filtering to the accelerometers filtered at 13 kHz. The accelerometers filtered at 30 kHz and 50 kHz were powered by a PCB Model 442C04 four-channel signal conditioner and filtered by two-stage analog "breadboard" filters that were designed and constructed at ARL. Tests were conducted with a conditioned 1-inch felt programmer at three different drop heights. Acceleration measurements for each height were initially conducted with unfiltered signals to provide a reference for the filtered signals and to ensure repeatability of the programmer.

³ Not an acronym

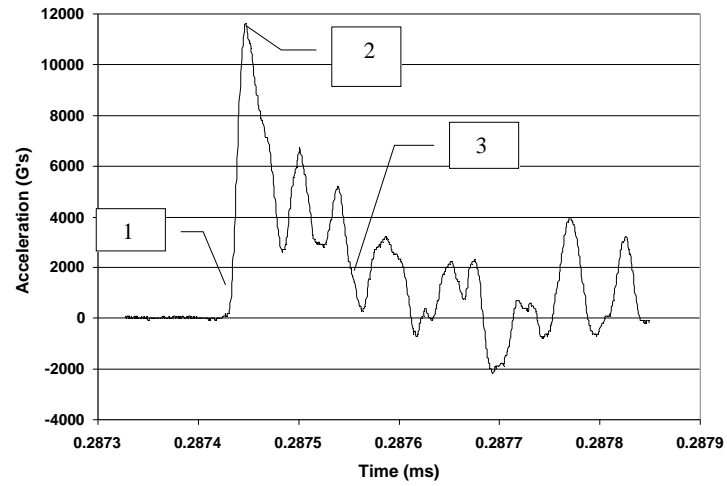
The accelerometer measurements were captured by a National Instruments data acquisition card Model DAQ 6110-E. This setup permits four-channel simultaneous sampling at a maximum rate of 4,000,000 samples/second and provides 12-bit resolution. Wavemetrics' IGOR Pro 4.0 signal analysis software was used to process the data on a personal computer that had 256 megabytes of random access memory and Windows New Technology (NT⁴) 4.0 operating system. Each test consisted of 1 second of data sampled at 0.5-microsecond intervals. No automatic trigger was available for this setup, and thus, triggering of the data acquisition was initiated by the user.

2.3 Shock Pulse Characterization

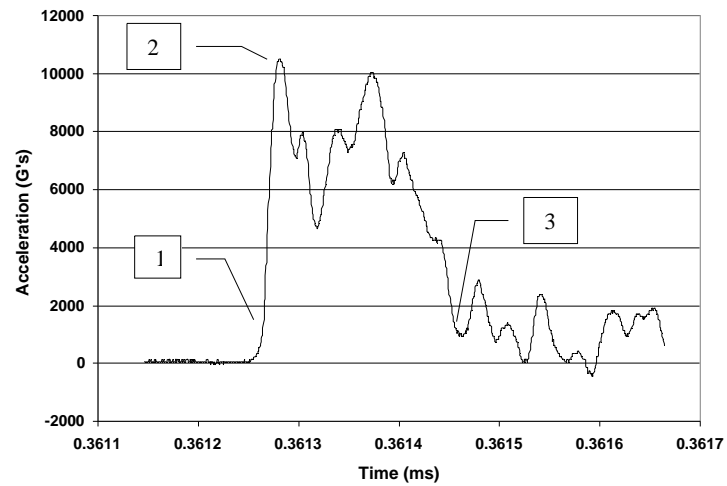
Typical shock pulses for tests conducted with 0.25-inch, 0.5-inch, and 1-inch felts are represented in Figure 3. The maximum acceleration is defined as the highest acceleration achieved during the primary shock. The duration for the shock pulses is defined by a 10% threshold of the peak acceleration. The start, maximum, and finish of the acceleration event are illustrated by labels 1, 2, and 3 in Figure 3. Application of this definition to the 0.25-inch programmer shock pulses is difficult because of the ringing in the shock pulses from the nearly metal-to-metal shock event. This method is an approximation and cannot be considered a highly accurate representation of the shock pulse duration, but it is effective as a first order estimate of gun launch durations.

The peaks displayed in Figure 3 that occur after the maximum acceleration are attributed to wave reflection transmitted through the table, fixture, and the bolts connecting these items. If an insufficient amount of programmer material is placed between the shock table and the reaction mass, the effects of this wave reflection can create accelerations so that some of the subsequent peaks have magnitudes approximate to those of the primary event. It was determined that increasing the felt thickness between the table and reaction base reduces the levels of these subsequent peaks. This method will also reduce the maximum acceleration and will increase the pulse duration of the acquired shock pulse and thus will require an adjustment in drop height to obtain a prescribed maximum acceleration and pulse duration. Another means of reducing the effect of wave transmission from the table to the test fixture is to place felt between the table and fixture. In this method, the accelerometer must be placed on the fixture rather than the table in order to measure the shock experienced by the test specimen. Quantified analysis for the effects of these methodical variations is outside the scope of the present study.

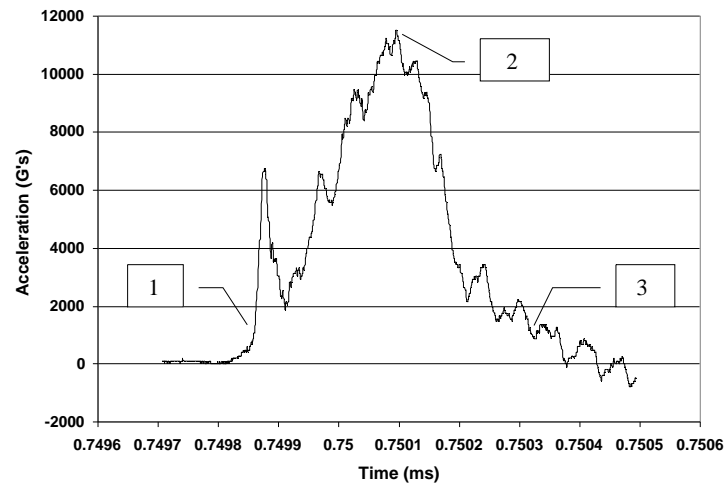
⁴Windows NT[®] is a registered trademark of Microsoft Corporation.



(a)



(b)



(c)

Figure 3. Typical shock pulse for a felt programmers: (a) 0.25 inch, (b) 0.5 inch, and (c) 1 inch.

3. Results

3.1 Programmers and Accelerometers

Shock tests were performed with 0.25-inch, 0.5-inch, and 1-inch thick programmers made of high density felt. A series of tests was conducted, starting with new felt and repeatedly shocking at a constant height. When a repeatable level of maximum acceleration was reached, another series of tests was performed on the same felt pad over a range of prescribed drop heights.

A series of shock tests was performed, starting with a new 0.25-inch thick felt programmer. The new programmer was conditioned in an experiment with a constant drop height of 23 inches. The accelerometers chosen for this segment were serial numbers (SN) 7227, 7232, 7233, and 7903. To examine the effect of signal conditioning on the 0.25-inch programmer data, two-stage analog filters with cut-off frequencies of 13 kHz, 30 kHz, and 50 kHz were used with accelerometers SN 7233, SN 7227, and SN 7232, respectively. The model 350B23 accelerometer, SN 7903, contains an internal mechanical filter with a cut-off frequency of 13 kHz. It is recognized that the reported measurement range (10,000 g's) for accelerometer SN 7903 was exceeded in this experiment.

The measured maximum accelerations for the 0.25-inch programmer conditioning experiment are shown in Figure 4. Each of the four accelerometer data sets exhibits an overall increase in maximum acceleration with increasing drop number until the maximum acceleration becomes repeatable with increasing shocks. This resultant behavior is attributable to the compression and corresponding increase in density of the fresh felt pad when it is exposed to repeated shocks. Specifically, the maximum accelerations increased from approximately 7,000 to 15,000 g's for accelerometers SN 7233 and 7903 during 23 consecutive shock tests. The increase in maximum acceleration measured by accelerometer SN 7227 was approximately 9,000 to 22,000 g's and that of accelerometer SN 7232 was approximately 15,000 to 35,000 g's. This variation in maximum acceleration underscores the need to precondition the felt programmer before shock tests are conducted by the programmer being shocked until the maximum acceleration results become repeatable. It is observed that the levels of the measurements from accelerometers SN 7233 and 7903 are similar and are smaller in magnitude than those of accelerometers SN 7227 and 7232. This decrease in acceleration level is attributed to the lower cut-off frequencies used on the measured signals from accelerometers SN 7233 and 7903.

The shock pulse durations for the 23-inch drop height experiment are shown in Figure 5. It is observed that the four accelerometers produced shock pulses with similar trends in duration with sequential drops. As expected with increasing maximum acceleration, the overall decrease in duration with increasing drop number can be attributed to compression in the felt programmers. Specifically, the duration decreased by an average of 46% during the conditioning of the

0.25-inch felt programmer. The figure shows that the two accelerometers that were externally filtered (SN 7233) and internally filtered (SN 7903) at 13 kHz and had similar duration levels during the last several shock tests, while the accelerometers filtered at 30 kHz (accelerometer SN 7227) and 50 kHz (accelerometer SN 7232) had similar duration levels.

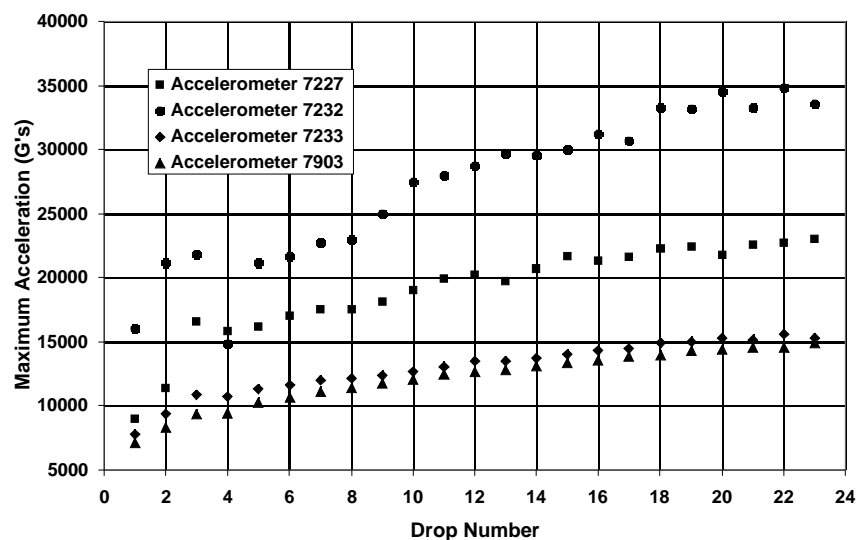


Figure 4. Maximum accelerations for 23-inch drops on the 0.25-inch programmer.

After the constant drop height test, the same felt programmer was subjected to a series of shock tests of increasing drop height. The same accelerometers and corresponding filters used in the conditioning of the 0.25-inch programmer were used in this series. The maximum acceleration results for this experiment are shown in Figure 6. As expected, the maximum acceleration increased with increasing drop height. The rise times for the shock pulses from the conditioned 0.25-inch felt programmer are displayed in Figure 7. Trend lines and corresponding equations are included in this figure. Again, there is an overall decrease in duration with increasing drop height for all the accelerometers. As observed from Figures 5 and 7, the durations for the accelerometers filtered at 13 kHz show similar levels, and these levels are greater than those of the other two accelerometers. These trends indicate that highly filtered accelerometers measurements provide larger shock pulse duration levels. Because of the large amount of ringing in the shock pulses from the 0.25-inch programmers, which arises from a nearly metal-to-metal shock, it is not possible to accurately quantify the duration of these shock pulses. Therefore, the author emphasizes that the durations presented for the 0.25-inch programmer experiments are approximations and can only be considered as first order values.

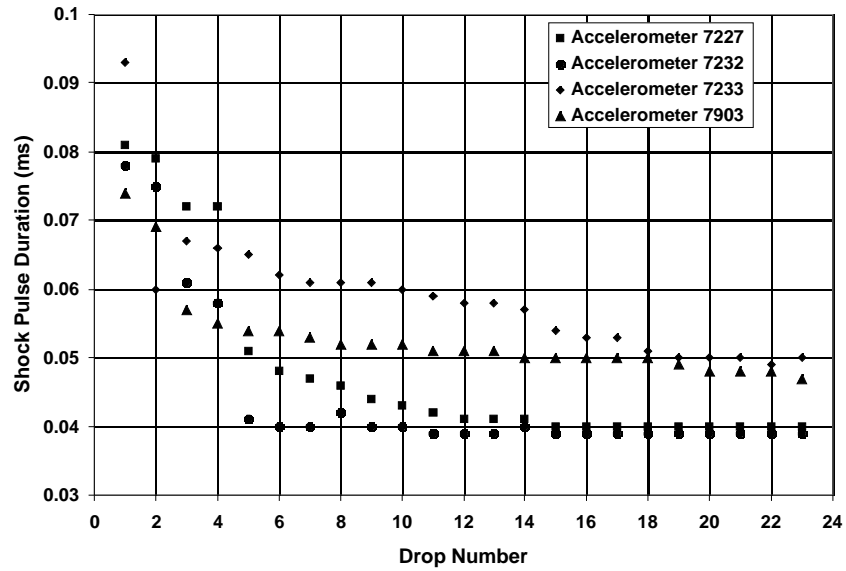


Figure 5. Shock pulse durations for 23-inch drops on the 0.25-inch felt programmer.

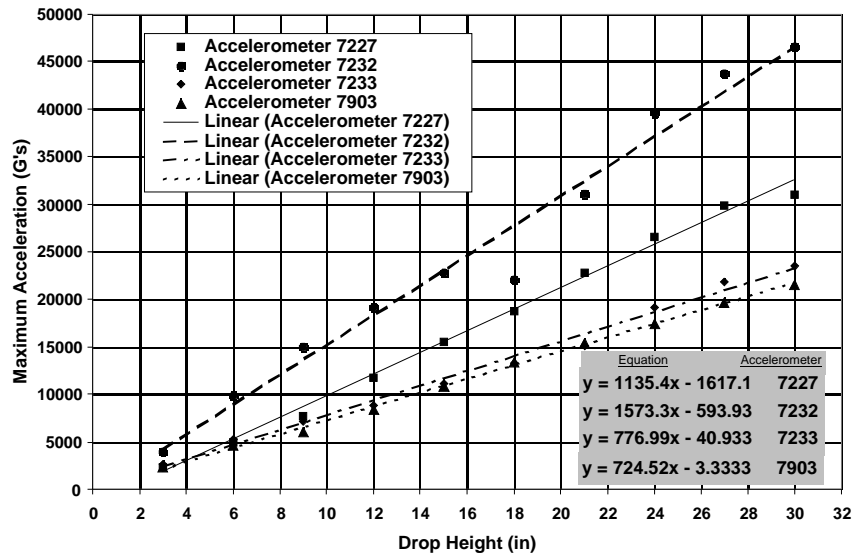


Figure 6. Maximum accelerations for the conditioned 0.25-inch felt programmer.

An experiment similar to that performed on the 0.25-inch thick programmer was conducted with a 0.5-inch thick felt pad. The new felt programmer was conditioned with a drop height of 47 inches. The accelerometers chosen for the conditioning segment were SN 7227 (filtered at 30 kHz) and SN 7903 (internally filtered at 13 kHz). Again, it is recognized that the maximum accelerations achieved in this series exceeded the reported measurement range (10,000 g's) of accelerometer SN 7903.

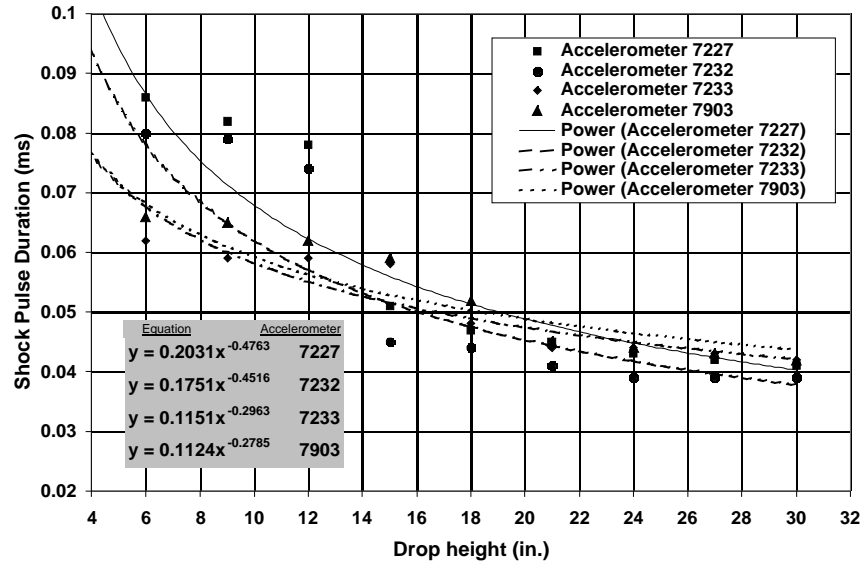


Figure 7. Shock pulse durations for the conditioned 0.25-inch felt programmer.

The measured maximum accelerations for the 47-inch drop height experiment on a 0.5-inch thick felt programmer are shown in Figure 8. The data from both accelerometers show an increase in maximum acceleration with increasing drop number until the maximum acceleration becomes repeatable with increasing shocks. Specifically, the maximum accelerations increased from approximately 3,000 to 13,000 g's during 24 consecutive shock tests. Figure 9 shows the shock pulse durations for the 47-inch drop height experiment. The pulse durations show an overall decrease for an increase in drop number. Specifically, the pulse durations decrease approximately 58% upon 24 consecutive drops. It is observed that the maximum accelerations measured by the accelerometer filtered at 13 kHz (accelerometer SN 7903) are less than those of the device filtered at 30 kHz for the 0.5-inch felt programmer.

A series of shock tests was performed on the conditioned 0.5-inch felt programmer with increasing drop height. Since the maximum accelerations for this experiment were expected to exceed the measurement range of accelerometer SN 7903, the accelerometers chosen for the evaluation of the conditioned programmer were SN 7232 (filtered at 13 kHz) and SN 7233 (filtered at 30 kHz). Figure 10 shows that for an increasing drop height from 6 inches to 94 inches, the 0.5-inch felt programmer yielded maximum accelerations of approximately 2000 g's to 30,000 g's. The figure also provides trend lines with corresponding equations for both data sets. It is observed from the figure that the acceleration levels measured by accelerometer SN 7233 are larger than those of SN 7232. This difference in maximum acceleration is attributable to the difference in cut-off frequency of the filters.

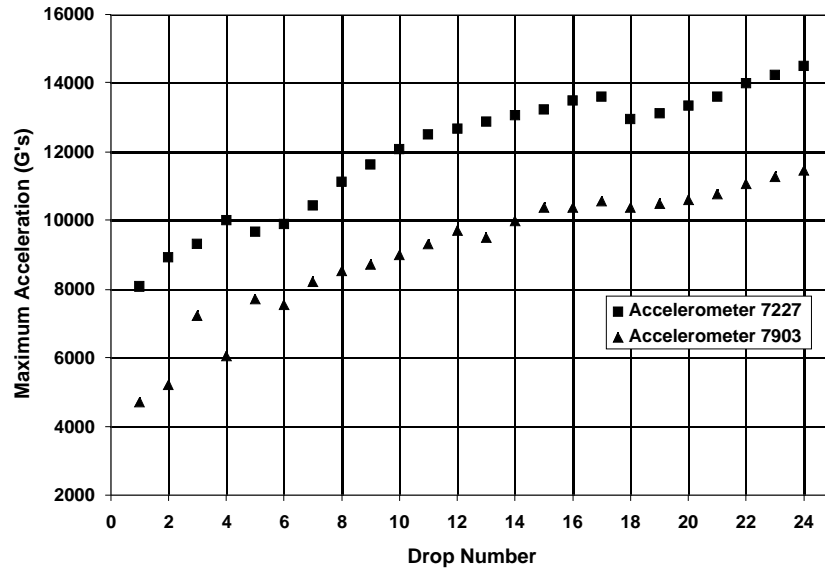


Figure 8. Maximum accelerations for 47-inch drops on the 0.5-inch programmer.

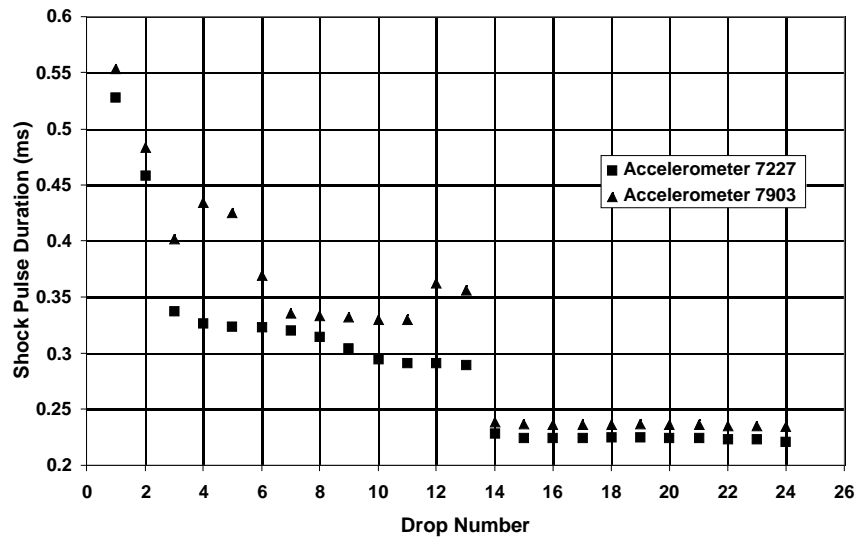


Figure 9. Shock pulse durations for 47-inch drops on the 0.5-inch programmer.

Figure 11 contains the shock pulse durations for the conditioned 0.5-inch thick felt programmer tests. This figure also provides a trend line and corresponding equations for both data sets. The trend in duration for both accelerometers shows a decrease for increasing drop height. It is observed that the durations for the last half of both data sets are nearly constant, even though the maximum accelerations continue to increase for an increase in drop height. This is because of the difficulty in interpreting shock pulse duration for the 0.5-inch felt programmer.

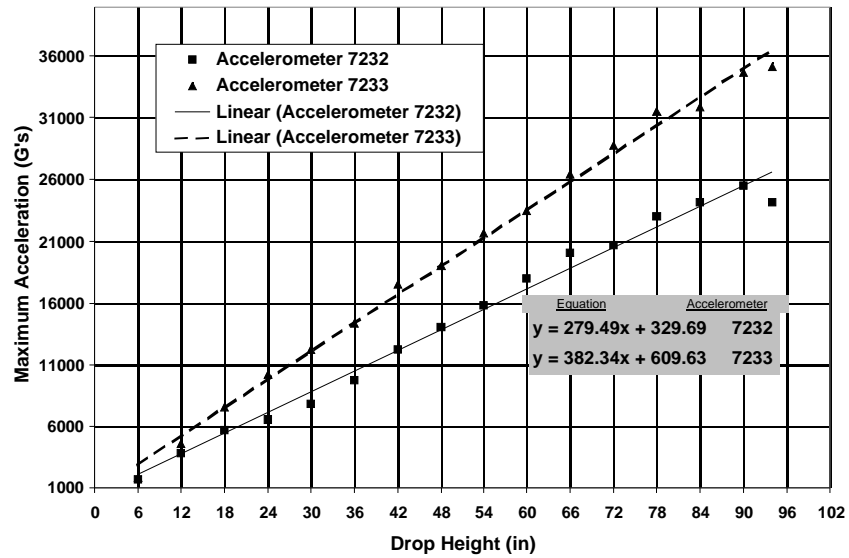


Figure 10. Maximum accelerations for conditioned the 0.5-inch felt programmer.

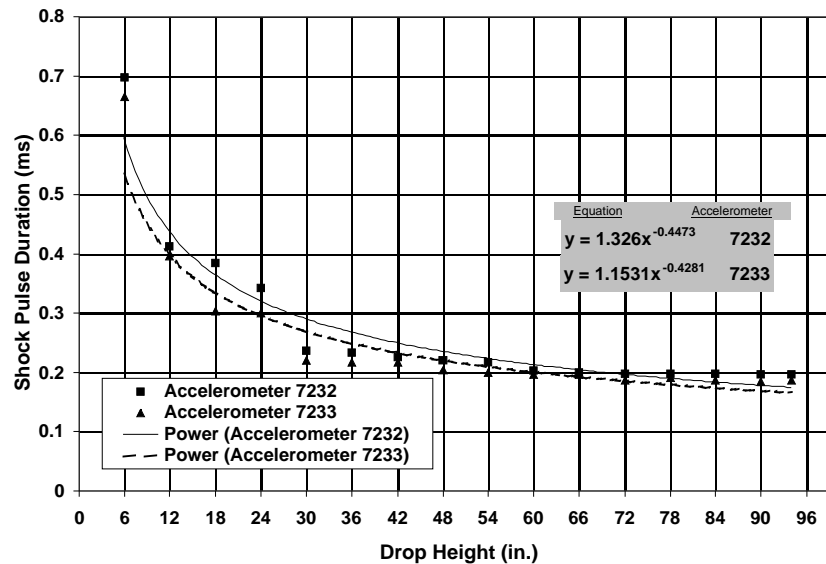


Figure 11. Shock pulse durations for the conditioned 0.5-inch felt programmer.

An experiment similar to that performed on the 0.25- and 0.5-inch thick programmers was conducted with a 1-inch thick felt pad. The new felt programmer was conditioned in an experiment that used a drop height of 94 inches. The accelerometers chosen for this segment were accelerometer SN 7227 (filtered at 50 kHz) and SN 7903 (internally filtered at 13 kHz). Again, it is recognized that the maximum accelerations achieved in this series exceeded the reported measurement range (10,000 g's) of accelerometer SN 7903.

The measured maximum accelerations for the 94-inch drop height experiment on a 1-inch thick felt programmer are displayed in Figure 12. The overall trend in maximum acceleration increases with successive drops until the measurements become repeatable at approximately 13,000 g's. In this series of tests, the programmer thickness was four times that of the 0.25-inch programmer experiment and accordingly, the drop height was increased by a factor of four. It is observed that the performance of accelerometer SN 7903 was in good agreement with the measurements of accelerometer SN 7227, even though many of the tests in this series exceeded the reported maximum measurement range of accelerometer SN 7903. Also, the maximum acceleration data from the 13-kHz filter inside accelerometer SN 7903 did not significantly deviate from those of SN 7227, which was filtered at 50 kHz. Furthermore, although the acceleration levels in the first half of this experiment were in the lower 10% of the Model 350B21 measurement range, accelerometer SN 7227 showed good agreement with the measurements of accelerometer SN 7903 for this portion of the series.

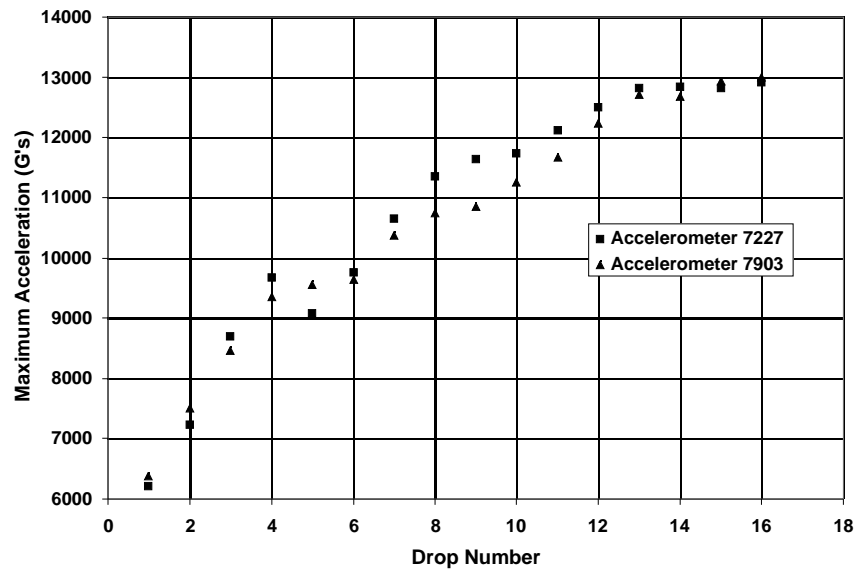


Figure 12. Maximum accelerations for 94-inch drops on the 1-inch felt programmer.

The durations for the measured shock pulses from the 94-inch drop height experiment are shown in Figure 13. As expected, the overall trend in pulse duration decreases for increasing drop number because of compression of the felt programmer. It is observed that the duration decreased more than 40% during the conditioning of the 1-inch felt programmer.

After the constant 94-inch drop height experiment, the same 1-inch thick felt programmer was subjected to a series of shock tests with increasing drop height. Figure 14 shows that the maximum acceleration increases from 500 g's to 13,000 g's for an increase in drop height from 7 inches to 94 inches. The two accelerometers used in this series of tests, accelerometers SN 7227

and 7903, showed good agreement in maximum acceleration for each drop height, as illustrated by the trend lines and corresponding equations.

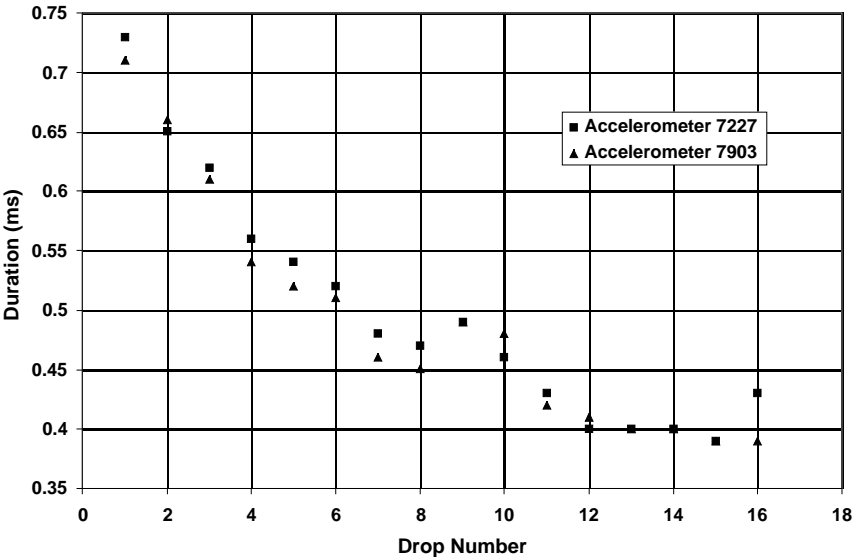


Figure 13. Pulse durations for 94-inch drops on the 1-inch felt programmer.

The pulse durations for the conditioned 1-inch thick felt programmer are shown in Figure 15, and it is observed that these durations decreased from 0.5 to 3 milliseconds. The trend displays an 87% decrease in duration for increasing drop height from 7 inches to 94 inches.

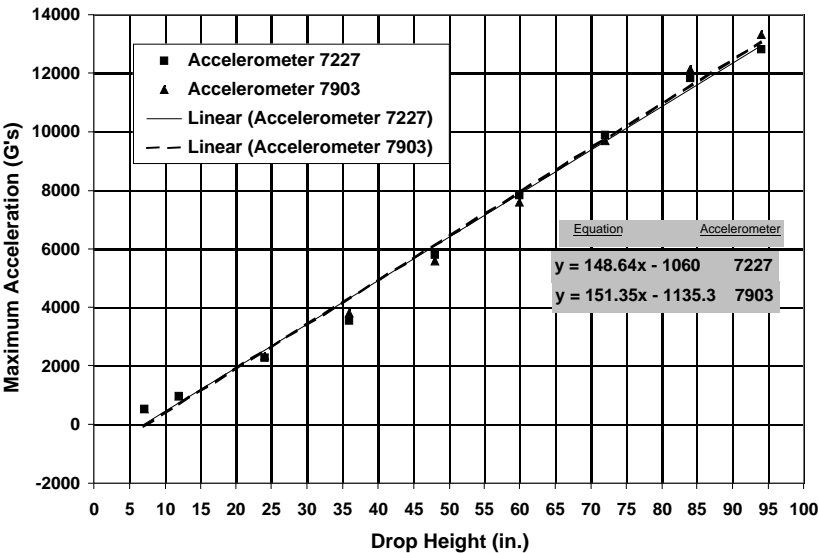


Figure 14. Maximum accelerations for the conditioned 1-inch felt programmer.

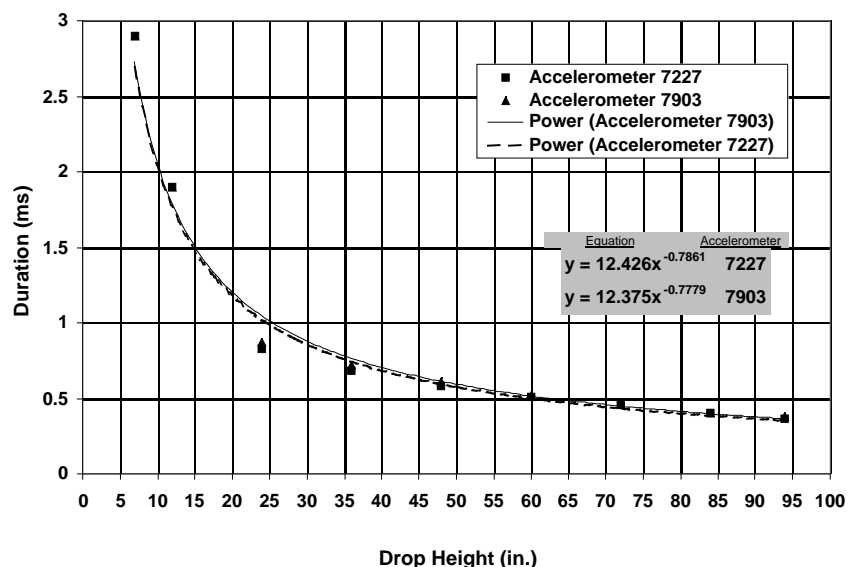


Figure 15. Pulse durations for the conditioned 1-inch felt programmer.

3.2 Filters

Electrical filters with prescribed cut-off frequencies are often employed to reduce deleterious effects on measured shock data, which arise from high frequency vibration transmission through the shock table and fixture mounting bolts. To determine the effect of cut-off frequency on measured shock pulses, a series of tests was conducted so that the accelerometer signals from three PCM Model 350B21 accelerometers were fed to two-stage analog filters with 13-kHz, 30-kHz, and 50-kHz cut-off frequencies. Acceleration measurements for each height were initially conducted with unfiltered signals to provide a reference for the filtered signals and to ensure repeatability of the programmer.

The 1-inch thick felt programmer used in this segment of the analysis was conditioned so that measured maximum accelerations were repeatable in subsequent shock tests of identical drop height. The tests were conducted with drop heights of 74, 54, and 28 inches, and the accelerometers used were PCM Model 350B21 devices SN 7227, 7228, and 7232. The assignment of filters was such that increasing cut-off frequency corresponded to increasing accelerometer sensitivity. Cut-off frequencies of 13 kHz, 30 kHz, and 50 kHz were used for the signals measured by accelerometers SN 7227, 7228, and 7232, respectively.

The maximum accelerations and corresponding durations achieved from the three drop heights are shown in Figures 16 and 17, respectively. Each data set on the graphs represents the mean of three shock tests. It is observed from Figure 16 that the maximum acceleration decreased when a filter was applied to the accelerometer output. As drop height increased, the difference in maximum acceleration magnitude between the filtered and unfiltered data for each accelerometer also increased. Furthermore, there is a decrease in maximum acceleration for decreasing cut-off

frequency in every data set. Specifically, the maximum acceleration decreased by 13% for the signal filtered at 13 kHz and it decreased 7% for the signal filtered at 50 kHz. These trends are underscored by the linear data fit and corresponding equations that are also shown in the figure. As illustrated by the trends shown in Figure 17, the corresponding pulse durations increase for increasing cut-off frequency.

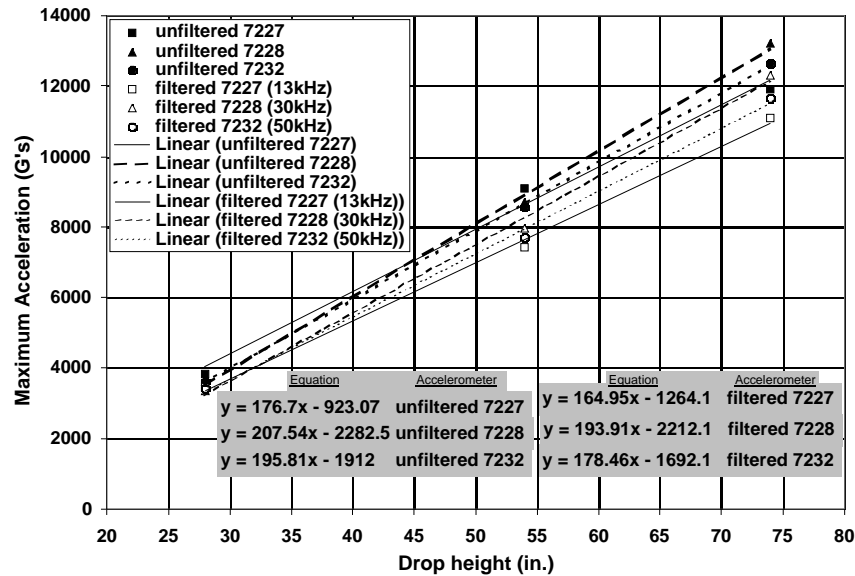


Figure 16. Effects of cut-off frequency on maximum acceleration.

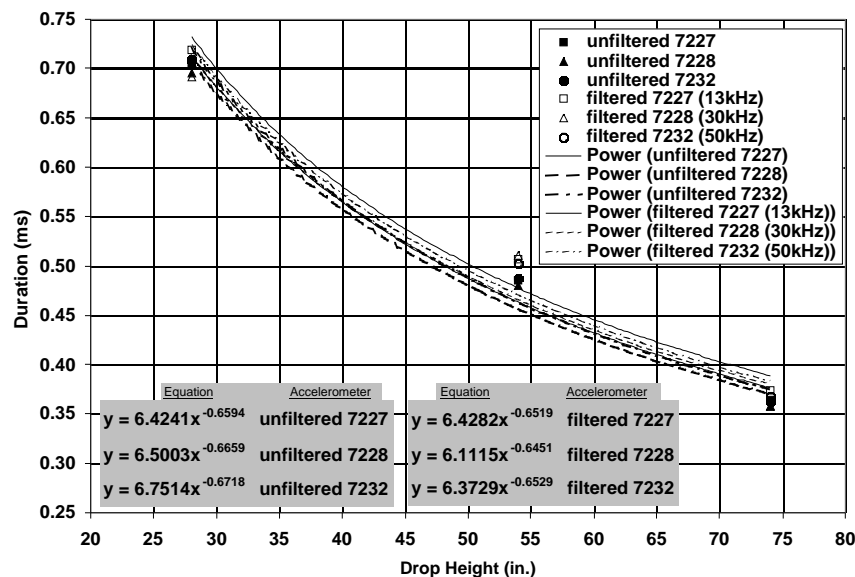


Figure 17. Effects of cut-off frequency on shock pulse duration.

4. Summary and Conclusions

The purpose of this evaluation was to calibrate and identify the performance capabilities of an MTS IMPAC66 shock test machine, Serial Number 118. The IMPAC66 shock test machine was designed to simulate high acceleration and/or high velocity scenarios. Shock tests performed by ARL are used to determine the survivability of electronic sensing packages when these are exposed to various launch environments. This study was accomplished by multiple series of shock tests to determine the effects of programmer thickness, accelerometer performance, and signal conditioning on the measured accelerations and corresponding shock pulse durations.

High density felt was the material used for programming all the shock pulses in this analysis. Tests were performed with 0.25-, 0.5-, and 1-inch thick felt pads. Inconsistencies in shock test results from the usage of fresh programmers led to a method of preconditioning the felt in order to obtain consistent performance. Series of tests were conducted, starting with new felt and repeatedly shocking at a constant height. When a repeatable level of maximum acceleration was reached, another series of tests was performed on the same felt pad over a range of prescribed drop heights.

The decelerations achieved during the shock tests conducted for this analysis were measured with PCB piezoelectric accelerometers. Two PCB accelerometer models were used for this study. The PCB model 350B21 is capable of measuring acceleration levels in the range of 0 to 100,000 g's and the PCB model 350B23 is capable of measuring acceleration levels of 0 to 10,000 g's. To determine the variation in acceleration measurement between similar model accelerometers, a series of test was conducted with four model 350B21 accelerometers used simultaneously. A comparison of results from the four accelerometers showed that when the obtained measurements are unfiltered, these devices exhibited a maximum variation in acceleration of 10% for the same shock test. Because of the large amount of noise in the unfiltered signals, a duration could not be accurately quantified for these shock pulses. Some of the shock tests performed for this report exceeded the manufacturer's suggested measurement range of the model 350B23 accelerometer (0 to 10,000 g's).

Experiments were performed to determine the effect of felt programmer thickness on measured maximum acceleration and shock pulse duration. A series of shock tests was performed, starting with a new felt programmer that was conditioned by consecutive shocks at a constant drop height. The results for this experiment show an overall increase in maximum acceleration with increasing drop number until the maximum acceleration becomes repeatable with increasing shocks. A new felt programmer of 0.25-inch thickness was conditioned with a constant drop height of 23 inches, and the maximum accelerations increased from an average of 10,000 to 25,000 g's during a series of 23 consecutive shock tests. The corresponding shock pulse durations for the 0.25-inch programmer conditioning experiment decreased from an average of

0.081 to 0.044 millisecond. A similar experiment was performed on a 0.5-inch thick felt programmer with a constant drop height of 47 inches. The maximum accelerations increased from approximately 6,000 to 13,000 g's during a series of 24 consecutive shock tests. The corresponding shock pulse durations for the 0.5-inch programmer decreased from approximately 0.55 to 0.23 millisecond. A third conditioning experiment was performed on a 1-inch thick felt programmer, and the maximum accelerations increased from approximately 6,000 to 13,000 g's during a series of 16 consecutive shocks at a constant drop height of 94 inches. The corresponding rise times for the 1-inch felt programmer decreased from approximately 0.75 to 0.4 millisecond during the series of shock tests. The variation in maximum acceleration and pulse duration for a fresh felt programmer exposed to a constant drop height underscores the need to precondition the felt programmer before shock tests are conducted, by shocking the programmer until the maximum acceleration results become repeatable.

After the constant drop height tests, the conditioned felt programmers were subjected to a series of shock tests of increasing drop height. The maximum accelerations for the 0.25-inch thick programmers increased from an average of 4,000 to 30,000 g's for increasing drop height from 6 to 30 inches. The corresponding rise times for the 0.25-inch thick programmer decreased from an average of 0.090 to 0.041 millisecond. The maximum accelerations for the 0.5-inch thick programmers increased from approximately 2,000 to 30,000 g's for increasing drop height from 6 to 94 inches. The corresponding shock pulse durations decreased from approximately 0.7 to 0.2 millisecond. Data for the 1-inch thick programmer showed an increase from approximately 500 g's to 13,000 g's for increasing drop height of 7 to 94 inches. The corresponding shock pulse durations decreased from 0.7 to 0.4 millisecond. It was difficult to accurately quantify shock pulse durations for the 0.25-inch felt programmer data because of the ringing in the pulses associated with a nearly metal-to-metal shock event. If shock pulse duration is of primary concern, it is recommended that a programmer of sufficient thickness be used to provide a shock pulse that permits a reasonably accurate interpretation of the shock pulse duration.

Electrical filters with prescribed cut-off frequencies are often employed to reduce deleterious effects on measured shock data, which arise from high frequency vibration transmission through the shock table and fixture mounting bolts. To determine the effect of cut-off frequency on measured shock pulses, a series of tests was conducted so that the accelerometer signals from four PCM Model 350B21 accelerometers were fed from the amplifier/signal conditioner to two-stage analog filters with 13-kHz, 30-kHz, and 50-kHz cut-off frequencies. The 1-inch thick felt programmer used in this segment of the analysis was conditioned so that measured maximum accelerations were repeatable in subsequent shock tests of identical drop height. The tests were conducted with drop heights of 74, 54, and 28 inches, and the assignment of filters was such that increasing cut-off frequency corresponded to increasing accelerometer sensitivity. Specifically, the maximum acceleration decreased by 13% for the signal filtered at 13 kHz, and it decreased 7% for the signal filtered at 50 kHz for the 74-inch drop height series. An examination of the data for the 54- and 28-inch drop height experiments reveals that the magnitude of maximum

acceleration showed a decrease in maximum acceleration for decreasing cut-off frequency in every data set. Consideration of the data from experiments performed on each programmer thickness reveals that the thinner felt programmers are more sensitive to filtering effects. Furthermore, the shock pulses obtained from unfiltered accelerometer measurements contain too much noise to permit reasonable quantification of shock pulse duration. The reader is advised to consult MIL-STD-202G to determine the appropriate filter for a specific application.

The objectives of this analysis were met in that data were obtained that can be used for post-refurbishment and post-maintenance performance verification of the IMPAC66 shock test machine, Serial Number 118. The data contained in this report provide the user with a baseline from which to prescribe an appropriate programmer thickness, drop height, and cut-off frequency in order to obtain a shock pulse of desired maximum acceleration and pulse duration. All tests in this analysis were performed with no payload fixed to the shock table, and the application of additional weight will provide results that vary from those published in this report.

References

Defense Supply Center, *Test Methods for Electronic and Electrical Component Parts*, MIL-STD-202G, Columbus, OH, February 8, 2002.

MTS Systems Corporation, *IMPAC66 HVA Shock Test Machine Reference Manual*, Minneapolis, MN, 1969.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE October 2002		3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Evaluation of the IMPAC66 Shock Test Machine, Serial Number 118				5. FUNDING NUMBERS PR: 1L162618H80	
6. AUTHOR(S) Childers, M.A. (ARL)					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons & Materials Research Directorate Aberdeen Proving Ground, MD 21005-5066				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSORING/MONITORING AGENCY REPORT NUMBER ARL-TR-2840	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The purpose of this evaluation was to calibrate and identify the performance capabilities of an MTS IMPAC66 shock test machine, Serial Number 118. This system is situated in Lab 1252 in Building 4600 of the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland. The IMPAC66 shock test machine was designed to simulate high acceleration and/or high velocity scenarios. The mechanism consists of a 33-pound high strength forged aluminum table that is accelerated via bungee cords onto a 450-pound steel reaction mass that is supported by a hydro-pneumatic suspension system. Programmers (shock-mitigating materials) are placed between the table and reaction base to provide a shock pulse of desired acceleration and duration and to prevent damage to the machine that may result from a metal-to-metal shock. Shock tests performed at ARL are used to determine the survivability of electronic sensing packages when these are exposed to various launch environments. Maximum accelerations associated with gun-launched munitions can range from 1500 g's to 30,000 g's. This study was accomplished by a series of shock tests to determine the effects of programmer thickness, accelerometer performance, and signal conditioning on the measured accelerations and corresponding shock pulse durations. The decelerations achieved during the shock tests conducted for this analysis were measured with PCB piezoelectric accelerometers. Results are given for a series of shock tests that evaluated three felt programmer thicknesses, two accelerometer measurement ranges, and three signal cut-off frequencies. The data contained in this report will be used for post-refurbishment and post-maintenance performance verification of the IMPAC66 Shock Test Machine Serial Number 118. Furthermore, the data curves contained in this report provide the user with a baseline from which to prescribe an appropriate programmer thickness, drop height, and cut-off frequency in order to obtain a shock pulse of desired maximum acceleration and pulse duration.					
14. SUBJECT TERMS high g shock testing shock mitigation				15. NUMBER OF PAGES 25	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT		